2I-2 Grass Swales

Grass swale (VA DCR, 1999)

BENEFITS Low = <30% Medium = 30-65% High = 65-100%			
	Low	Med	High
Suspended Solids		■	
Nitrogen	■	■	
Phosphorous	■	■	
Metals		■	■
Bacteriological	■		
Hydrocarbons	*	*	*

* Insufficient Data

Description: Grass swales are designed to convey stormwater runoff at a non-erosive velocity, as well as enhance its water quality through infiltration, sedimentation, and filtration. Check dams can be used within the swale to slow the flow rate, promote infiltration, and create small, temporary ponding areas. The vegetation covering the side slopes and channel bottom provide a filtration surface as the runoff is slowly conveyed to a downstream discharge location. The vegetation also serves to reduce flow velocities.

Typical uses:

- Manages runoff from residential sites, parking areas, and along perimeter of paved roadways.
- Located in a drainage easement at the rear of side of residential parcels.
- Used as a pre-treatment conveyance for other water quality BMPs.
- Road shoulder rights-of-way; used adjacent to paved roadways in place of curb and gutter, or used as a conveyance channel on the back side of curb-cut openings.

Advantages/benefits:

- Mitigates runoff from impervious surfaces; removes sediment and pollutants to improve water quality
- Reduce runoff rate and volume in highly impervious areas; reduced runoff velocity.
- Provides for groundwater recharge if design and site soils provide sufficient infiltration.
- Good option for small area retrofits for residential or institutional areas of low to moderate density; linear configuration works well with highway or residential street applications.

Disadvantages/limitations:

- Cannot alone achieve 80% goal reduction of TSS.
- Sediment and pollutant removal sensitive to proper design of slope and maintaining sufficient vegetation density; possible re-suspension of sediment.
- Limited to small areas (< 5 acres); cannot be used on steep slopes (> 6%).
- Higher maintenance than curb and gutter systems.

Maintenance requirements:

- Needs routine landscape maintenance; maintain grass height of approximately 4-6 inches.
- Inspect annually for erosion problems; remove accumulated trash and debris.
- Remove sediment from forebay and channel (if necessary).

A. Description

Grass swales, also called biofilters, are typically designed to provide nominal treatment of runoff as well as meet runoff velocity targets for the water quality design storm. Grass swales are well-suited to a number of applications and land uses, including treating runoff from roads and highways and pervious surfaces.

Grass swales differ from the enhanced dry swale design in that they do not have an engineered filter media to enhance pollutant removal capabilities, and therefore have a lower pollutant removal rate than a dry or wet (enhanced) swale. Grass swales can partially infiltrate runoff from small storm events in areas with pervious soils. When properly incorporated into an overall site design, grass swales can reduce impervious cover, accent the natural landscape, and provide aesthetic benefits.

When designing a grass swale, the two primary considerations are channel capacity and minimization of erosion. Runoff velocity should not exceed 1 fps during the peak discharge associated with the water quality design rainfall event, and the total length of a grass swale should provide at least five minutes of residence time. To enhance water quality treatment, grass swales must have broader bottoms, lower slopes, and denser vegetation than most drainage channels. Additional treatment can be provided by placing check dams across the channel, below pipe inflows and at various other points along the channel.

B. Stormwater management suitability

Grass swales can provide effective control under light to moderate runoff conditions, but their ability to control large storms is limited. Therefore, they are most applicable in low- to moderately-sloped areas, or along highway medians as an alternative to ditches or curb and gutter drainage (Boutiette and Duerring, 1994). Their performance diminishes sharply in highly urbanized settings, and they are generally not effective enough to receive construction stage runoff where high sediment loads can overwhelm the system (Schueler et al., 1992). Grass swales are often used as a pre-treatment measure for other downstream BMPs, particularly infiltration devices (Driscoll and Mangarella, 1990). Grass swales are typically shallow, vegetated, man-made conveyance channels designed such that the bottom elevation is above the water table to facilitate the infiltration of runoff to the soil. The vegetation covering the side slopes and channel bottom provide a filtration surface as the runoff is collected and slowly conveyed to a downstream discharge location. Swales provide additional treatment of the stormwater runoff as water moves through a subsoil matrix and infiltrates into the underlying soils. The vegetation also serves to reduce flow velocities. Swales can be either dry or wet; dry swales are more desirable where standing water is not wanted, such as residential areas; wet swales can be used where standing water does not create a nuisance and where the groundwater is close enough to the surface to maintain a shallow permanent pool between storm events. An advantage of wet swales is the ability to include wetland vegetation to assist in pollutant removal (U.S. EPA 1999b).

C. Pollutant removal capabilities

Pollutants are removed in swales by the filtering action of grass, deposition in low velocity areas, or by infiltration into the subsoil. The primary pollutant removal mechanism is through sedimentation of suspended materials. Therefore, TSS and adsorbed metals are most effectively removed through a grass swale. Removal efficiencies reported in the literature vary, but generally fall into the low to medium range, with some swale systems recording no water quality effects at all. Table 1 presents pollutant removal efficiencies for swale lengths of 200 feet and 100 feet. Although research results varied, these data clearly indicate greater pollutant removal at longer swale lengths. In general, the current literature reports that a well-designed, well-maintained swale system can be expected to remove 70% of TSS, 30% for total phosphorus (TP), 25% for total nitrogen (TN), and 50 to 90% for trace metals (Barret et al., 1993 and GKY and Associates, Inc., 1991). The nitrogen removals may be fairly optimistic, given that studies conducted by Yousef et al. (1985) and others produced negative nitrogen removal in many cases. It is theorized that the outwelling of nitrogen from grass clippings and other organic materials from the swale produced these results.

Seasonal differences in swale performance can be important. In temperate climates, fall and winter temperatures force vegetation into dormancy, thereby reducing uptake of runoff pollutants, and removing an important mechanism for flow reduction. Decomposition in the fall and the absence of grass cover in the winter can often produce an outwelling of nutrients, and exposes the swale to erosion during high flows, increasing sediment loads downstream. Pollutant removal efficiencies for many constituents can be markedly different during the growing and dormant periods (Driscoll and Mangarella, 1990).

Table 1: Swale pollutant removal efficiencies

Pollutant removal efficiencies (%)								
Design	**Solids**	**Nutrients**		**Metals**			**Other**	
	TSS	TN	TP	Zn	Pb	Cu	FOG	COD**
200-ft swale	83	25*	29	63	67	46	75	25
100-ft swale	60	*	45	16	15	2	49	25
* Some swales (100-ft systems) show negligible or negative removal for TN ** Limited data								

Sources: Barret et al., 1993; Schueler et al, 1991; Yu,1993; and Yousef et al., 1985

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling and professional judgment.

- Total suspended solids: 50%
- Total phosphorus: 25%
- Total nitrogen: 20%
- Fecal coliform: insufficient data
- Heavy metals: 30%

D. Application and feasibility

The grass swale consists of a broad, mildly-sloped open channel designed to maintain a minimum residence time of 10 minutes for the water quality storm (Figure 1). Grass swales have traditionally been utilized only for stormwater conveyance purposes. However, the design provides capacity to convey a larger storm (usually the 10-year frequency storm); as well as protection against erosion for smaller, more frequent storms (usually the 2-year event). Water quality treatment in standard grass swales is provided by managing the slope and vegetation in the channel to slow the velocity to ~1 fps for the water quality design storm (≤ 1.25 inches). The design for a grass swale is flow-rate based.

E. Grass swales for pre-treatment

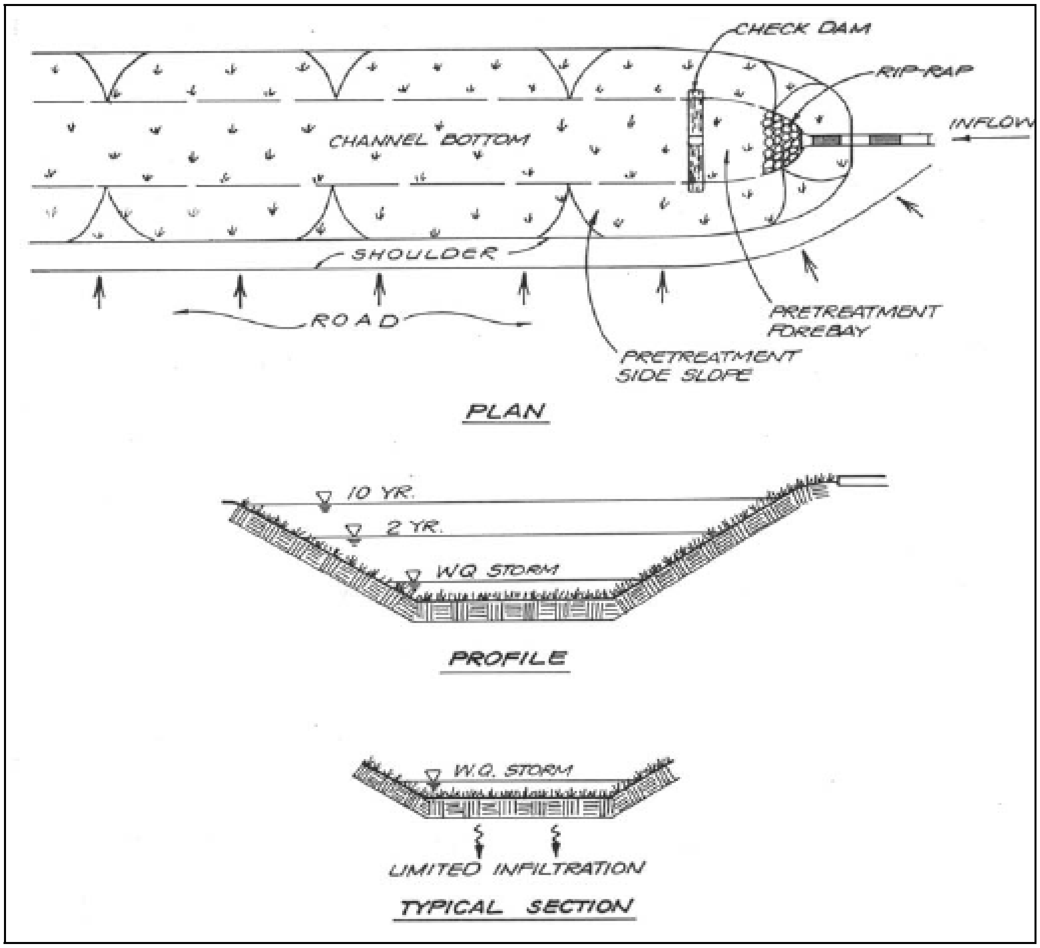
A number of other structural controls, including bioretention areas and infiltration trenches, may utilize a grass swale as a pre-treatment measure. The length of the grass swale depends on the drainage area, land use, and channel slope. Table 2 provides sizing guidance for grass swales for a 1-acre drainage area. The minimum length of a grass swale should be 20 feet.

Table 2: Grass swale sizing guidance

Parameter	Upstream imperviousness					
	≤ 33%		34-66 %		≥ 67%	
Slope (max = 4%)	< 2%	>2%	<2%	>2%	<2%	>2%
Grass swale minimum length (feet)*	25	40	30	45	35	50
*assumes 2-foot wide bottom width						

Source: CRC, Claytor and Schuler, 1996

Figure 1: Configuration of grass swale



Source: CRC, Claytor and Schuler, 1996

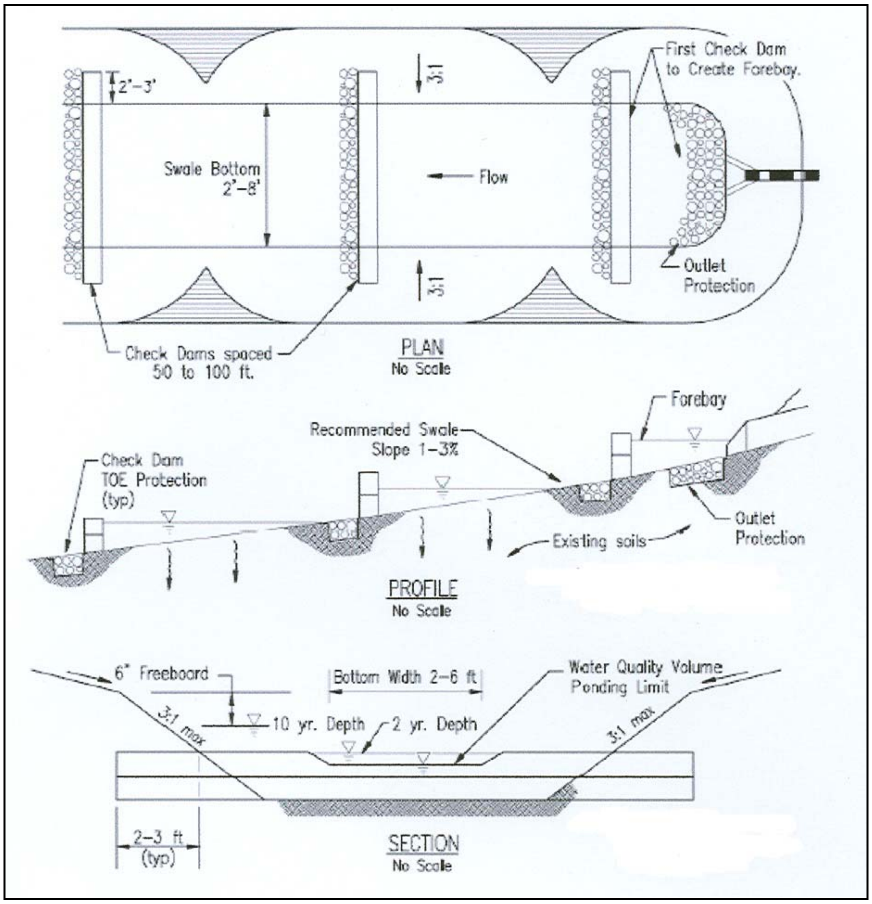
F. Check dams

Check dams are used in swales for two reasons: to increase pollutant removal efficiency and/or to compensate for steep longitudinal slope. The dams should be installed perpendicular to the direction of flow and anchored into the slope of the channel. The side slopes of the check dams should be between 5:1 and 10:1 to facilitate mowing operations. The berm height should not exceed 2 feet, and water detained behind the berm should infiltrate into the soils within 24 hours (Colorado Department of Transportation, 1992). Figure 2 shows an example of check dams erected at regular intervals to maintain a shallower, uniform slope (VA DEC, 1999). With this configuration, energy-dissipating and flow-spreading riprap is often used across check dams and for a short distance downstream at the toe of the drops. Check dams should be spaced so that the toe of the upstream dam is at the same elevation as the top of the downstream dam. Check dams can be constructed using earth, riprap, gabions, railroad ties, or pressure-treated wood logs. Figure 3 provides typical check dam configurations for a riprap and a half-round corrugated metal pipe check dam (VA DEC, 1999). For best performance, check dams should have a level upper surface rather than the uneven surface of a riprap check dam. Earthen check dams are not recommended, due to erosion potential and high maintenance effort.

Figure 2: Grass swale with check dams (berms)

Source: VA DEC, 1999

Figure 3: Typical swale with check dam configuration



Source: VA DEC, 1999

G. Channel design criteria

The design approach consists of three criteria for sizing grass swales for stormwater quality treatment, while also accommodating larger storms:

- The channel is initially designed, based on the treatment principles of small storm hydrology for the water quality storm (see Section 2C-7).
- The channel design is then checked against the larger 2-year storm to ensure a non-erosive condition.
- Finally, the capacity for conveyance of the 10-year frequency storm is checked and a minimum freeboard is applied.

The design procedure is a rate-based sizing criteria which uses Manning's equation to compute velocities and depths, based on specified channel geometry and slope. Figure 4 illustrates the design components of the grass swale. The specific design considerations are presented below, and a summary is provided in Table 3.

1. **General design criteria.**

   a. Grass swales should generally be used to treat small drainage areas of less than 5 acres. If the practices are used on larger drainage areas, the flows and volumes through the channel become too large to allow for filtering and infiltration of runoff.
   b. Grass swales should be designed on relatively flat slopes of less than 4%, channel slopes between 1-2% are recommended.
   c. Grass swales can be used on most soils with some restrictions on the most impermeable soils. Grass swales should not be used on soils with infiltration rates less than 0.3 inches per hour if infiltration of small runoff flows is intended.
   d. A grass swale should accommodate the peak flow for the water quality design storm – Qwq (see Section 2C-7).
   e. Runoff velocities must be non-erosive. For the Qwq, the velocity should be ≤ 1 fps. The full-channel design velocity will typically govern.
   f. A minimum five-minute residence time is recommended for the water quality peak flow. Residence time may be increased by reducing the slope of the channel, increasing the wetted perimeter, or planting a denser grass (raising the Manning's n).
   g. The depth from the bottom of the channel to the groundwater should be at least 2 feet to prevent a moist swale bottom or contamination of the groundwater.
   h. Check dams within the channel will maximize retention time (Figure 2).
   i. Select a grass that can withstand relatively high-velocity flows at the entrances, and both wet and dry periods. See SUDAS specifications for a list of appropriate grasses for use in Iowa.

2. **Shape.** The channel should be trapezoidal or parabolic in shape. The trapezoidal cross section is the easiest to construct and a more efficient hydraulic configuration. However, since channels tend to become parabolic in shape over time, a channel originally designed as a trapezoidal section should also be checked against parabolic sizing equations as a long-term functional assessment. The criteria presented in this section assume a trapezoidal cross section. Note that the same design principles will govern parabolic cross sections, except for the cross sectional geometry.

3. **Bottom width.** For a trapezoidal cross section, size the bottom width between 2 and 8 feet. The 2-foot minimum allows for construction considerations and ensures a minimum filtering surface for water quality treatment. The 8-foot maximum prevents shallow flows from concentrating and potentially eroding channels, thereby maximizing the filtering by vegetation. Widths up to 12 feet may be used if separated by a dividing berm or structure to avoid braiding. The bottom width is a dependent variable in the calculation of velocity based on Manning's equation. If a larger channel is needed, the use of a compound cross section is recommended.

4. **Manning's n value.** The roughness coefficient, n, varies with the type of vegetative cover and flow depth. At very shallow depths, where the vegetation height is equal to or greater than the flow depth, the n value should be approximately 0.15. This value is appropriate for flow depths up to 4 inches. For higher flow rates and flow depths, the n value decreases to a minimum of 0.03 for grass swales at a depth of approximately 12 inches. The n value must be adjusted for varying flow depths between 4 and 12 inches (see Figure 5 for variable n values with varying depths).

5. **Side slopes.** The side slopes should be flat as possible to aid in providing pre-treatment for lateral incoming flows and to maximize the channel filtering surface. Steeper side slopes are likely to have potential for erosion from incoming lateral flows. A maximum slope of 3:1 is recommended (33%); a 4:1 slope is preferred where space permits.

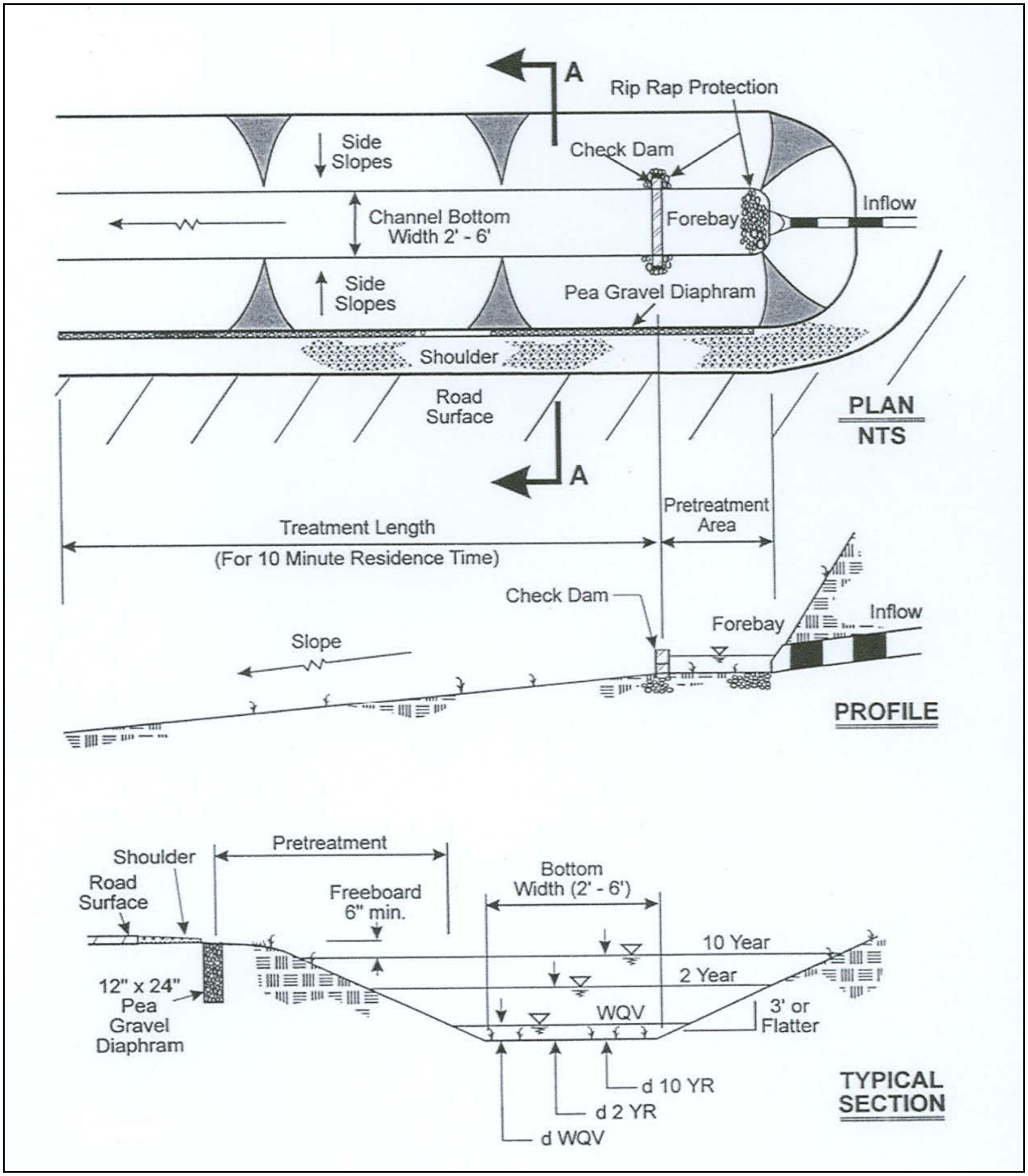
6. **Channel longitudinal slope.** The slope of the channel should be steep enough to ensure uniform flow and that which can be constructed using conventional construction equipment without ponding, but not steeper than 4%. A minimum slope of 1% is recommended.

7. **Flow depth.** Maximum depth of flow no greater than one-third of the vegetation height for infrequently mowed swales, or no greater than one-half of the vegetation height for regularly mowed swales, up to a maximum of 4 inches. The maximum flow depth for water quality treatment should be approximately the same as the height of the grass. Since most channels will be mowed relatively infrequently, the vegetation may reach heights of 6 inches or more. However, since higher grass will likely flatten during higher flows, a maximum flow depth of 4 inches is recommended for water quality design. The flow depth for the 2-year and 10-year storms will depend on the flow rate and channel geometry.

8. **Flow velocity.** The maximum flow velocity for water quality treatment should be sufficiently low to provide adequate residence time within the channel. A maximum flow velocity of 1 fps for water quality treatment is required. The maximum flow velocity for the 2-year storm should be non-erosive (a rate of 4-5 fps is generally recommended). The permissible velocities of several grass species are listed in Table 4. Velocity values are purely guidelines and may not always be representative of field conditions. The 10-year permissible velocity may be somewhat higher due to the low frequency of occurrence. A permissible maximum rate of approximately 7 fps for this event is recommended.

9. **Length of channel**. Generally grass swale length (for conveyance) is a function of site drainage constraints and a required length is not necessary. However, for water quality treatment, a minimum residence time of 10 minutes should be reached to facilitate filtering. The minimum length required for water quality treatment grass swales is equal to the velocity, in feet per second, multiplied by the minimum residence time of 600 seconds.

Figure 4: Configuration and design components of a grass swale for water quality treatment



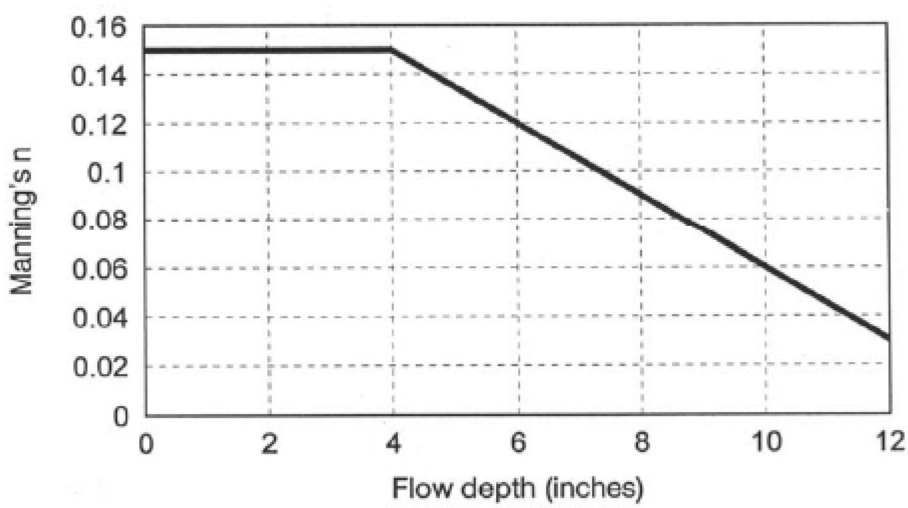
Source: Claytor and Schuler, 1996

Table 3: Design criteria for trapezoidal grass swales for water quality treatment

Parameter	Design Criteria
Bottom width	2-ft minimum, 6-ft maximum*
Side slopes	3:1 or flatter
Channel longitudinal slope	1% minimum; 4% maximum
Flow depth	4 inches for water quality treatment
Manning's n value	0.15 for water quality treatment (depth < 4 inches); varies from 0.15-0.03 for depths of 4-12 inches; 0.03 minimum for depths > 12 inches (see Figure 5)
Flow velocity	1 fps for water quality treatment; 4-5 fps for 2-yr storm; 7 fps for 10-yr storm
Length	Length necessary for 10-minute residence time
* Widths up to 12 feet are allowable when using a division structure to avoid meandering concentrated flows	

Source: Adapted from Claytor and Schuler, 1996

Figure 5: Variable Manning's n with flow depth



Source: Claytor and Schuler

Table 4: Selecting maximum permissible swale velocities for stability

		Maximum Velocity (fps)	
Cover Type	**Slope (%)**	**Erosion-resistant soils**	**Easily-eroded soils**
Kentucky blue grass; Tall fescue	0-5	6	5
Kentucky blue grass; Rye grasses	5-10	5	4
Grass – legume	0-5	5	4
Mixture	5-10	4	4
Red fescue	0-5	3	2.5

Source: Temple et al, 1987

H. Design procedure

The following steps are recommended for completing a grass swale design:

- Determine design flow rate to the system (Qwq)
- Determine the slope of the system
- Select a swale shape
- Determine required channel width
- Calculate the cross sectional area of flow
- Calculate the velocity of channel flow
- Calculate swale length
- Select swale location based on the design parameters
- Select a vegetation cover for the swale
- Check for swale stability

1. **Step 1: Determine design flow rate.**

   a. Determine the WQv using a design storm depth of 1.25 inches, or use the 90% rule to select rainfall depth for the water quality storm (refer to Parts 2B and 2C).

   b. Compute the peak rate of discharge (Qwq) for the water quality storm, based on the procedures identified in Section 2C-7. Note: This calculation can be done using WINTR-55 after a custom CN is computed using the water quality design storm depth (1.25 inches).

   c. The design storm is subject to local regulations, and thus may vary on a local basis.

   d. Unless runoff from larger events is designed to bypass the swale, consideration must be given to the control of channel erosion and destruction of vegetation. A stability analysis for larger flows (up to the 100-yr, 24-hour) must be performed. Runoff quantity and design flows can be estimated using a variety of mathematical, graphical, and computerized techniques.

   e. Use the Qwq to size the channel, maintaining design criteria parameters noted in Table 3.

   f. Determine the velocity (fps) for the Qwq and n=0.15 for channel widths of 2 feet, 4 feet, and 6 feet, or use computer model which solves Manning's equation or other open channel flow equations.

   g. Compute 2-year and 10-year frequency storm event peak discharges using NRCS WINTR-55.

   h. Check 2-year velocity for erosive potential (adjust geometry if necessary, and re-evaluate WQv design parameters).

   i. Check 10-year depth and velocity for capacity (adjust geometry if necessary, and re-evaluate WQV and 2-year design parameters).

   j. Provide minimum freeboard above 10-year stormwater surface elevation (6 inches minimum, recommended).

2. **Step 2: Determine the slope of the system.** (See Table 3). The slope of the swale will be somewhat dependent on where the swale is placed, but should be between the stated criteria of 1-4%. An optimum slope of 1.5-2% is desired. With slopes less than 2%, the use of under drainage may be required. If the slope is between 4-6%, vertical drops of 6-12 inches will be required using check dams/berms at 50- to 100-foot intervals. Energy dissipating and flow spreading riprap will be needed across check dams and for a short distance downstream of the toe drops. If the slope is greater than 6%, the grade will need to be traversed to reduce the slope of any segment to below 4% preferably, or to below 6% with check dams.

3. **Step 3: Select a swale shape.** Normally, swales are designed and constructed in a trapezoidal shape, although alternative designs can be parabolic, rectangular, or triangular. Trapezoidal cross sections would be preferred because of relatively wider vegetative areas and ease of maintenance. This also avoids the sharp corners present in v-shaped and rectangular swales, and offer better stability than the vertical walls of rectangular swales. A parabolic shape is best for erosion control, but is hard to construct. Trapezoidal shapes tend to become parabolic over time, due to the growth of vegetation and settlement of solids (Horner, 1988). Unless space is a problem, the design process should begin assuming a trapezoidal shape. The remainder of the design process assumes that a trapezoidal shape has been selected. A minimum side slope of 3:1 or flatter should be used; a side slope of 4:1, or even 5:1, would be preferred. The wider the wetted area of the swale, the slower the flow.

4. **Step 4: Determine required channel width.** Estimates for channel width for the selected shape can be obtained by applying Manning's equation (Equation 2). Figure 6 presents channel geometry and equations for a trapezoidal swale, the most frequently-used shape. A Manning's n value of 0.15-0.2 is recommended for routine swales that will be mowed with some regularity. For swales that are infrequently mowed, a Manning's n value of 0.24 is recommended. A higher n value can be selected if it is known that vegetation will be very dense. Figure 7 provides a range of n values.

   a. **Continuity Equation.**

   $Q = V \times A$ **Equation 1**

   where V = the mean velocity (fps) and A = the flow cross sectional area normal to the direction of the flow (ft^2).

   The cross sectional area is the product of the channel width and the depth of flow in the channel. The depth of flow in the channel for a uniform discharge is the normal depth. At normal depth the slope of the invert (channel bottom), the slope of the HGL, and the slope of the EGL are equal and parallel to each other. Normal depth for a given discharge can be determined using the Manning equation. Velocities for grass swales are calculated with Manning's equation, but the characteristic dimension now becomes the hydraulic radius.

   b. **Manning's Equation.**

   $V = (1.49/n)\, R^{2/3} S^{1/2}$ **Equation 2**

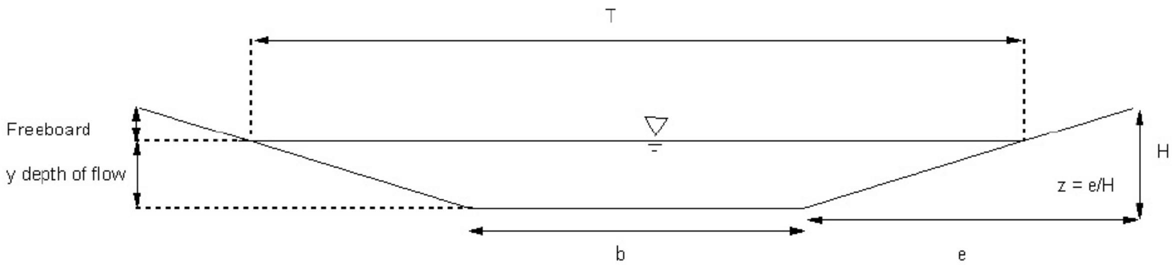
   where V = the mean velocity (fps), R = the hydraulic radius (ft), S = the slope of the energy line (channel invert), and n = the coefficient of roughness.

   Further, hydraulic radius, R, of the swale is defined as:

R = A/P

where A = cross sectional area of swale (ft^2), and P = wetted perimeter of swale (ft).

Figure 6: Channel and flow geometry for a trapezoid swale



c. **Side slope.**

Z = e / H **Equation 3**

d. **Cross sectional area.**

$A = by + zy^2$ **Equation 4**

e. **Top width.**

T = b + 2Hz **Equation 5**

f. **Wetted perimeter.**

$P = b + 2y\ [1+z^2]^{0.5}$ **Equation 6**

g. **Hydraulic radius.**

$R = A/P = (by + by2)/\ [b + 2y\ [1+z^2]^{0.5}]$ **Equation 7**

h. **Swale depth.**

H = y + freeboard **Equation 8**

where y = flow depth, b = bottom width, and e = side width of trapezoidal channel.

Manning's n values are not constant, but vary widely with depth of flow as shown in Figure 5. Vegetated channels are grouped into retardance classes A through E shown in Table 5. In each of these retardance classes, Manning's n is shown as a function of product of velocity V in fps and hydraulic radius R in ft. Using these curves, Ree (1949) developed nomographs for solving Manning's equation for each retardance class. An example is shown in Figure 8 for Retardance class C. Nomographs for other retardance classes are given in Haan et al. (1994).

i. Manning's equation (Equation 2) can be solved for flow by combining with the continuity equation (Equation 1).

j. The bottom width of the trapezoid cannot be solved directly so the solution is iterative. However, the calculations can be solved fairly quickly using a spreadsheet with iterative capabilities and the ability to vary only certain variables.

k. Typically, flow depth, y, is set at 3-4 inches maximum (Table 3). Flow depth can also be estimated by subtracting 2 inches from the expected grass height, if the grass type and the height it will be maintained is known. Values lower than 3-4 inches can be used, but doing so will increase the computed width (T or b) of the swale. Flow depth is subject to a stability check as described below.

l. The computed bottom swale width should be between 2-8-feet. Relatively wide swales (those wider than 8 feet are more susceptible to flow channelization and are less likely to have uniform sheet flow across the swale bottom for the entire swale length. A practical minimum swale width for trapezoidal swales should also be established for ease of maintenance, e.g., to facilitate swale mowing with standard lawn mowers. Therefore, if b for a trapezoid swale is greater than 8 feet, investigate either (a) the probability for channelization given flow spreader device(s) to be used and swale maintenance practices, or (b) methods by which the design flow (Q) can be reduced. Since length may be used to compensate for width reduction (and vice versa) so that the area is maintained, the swale width can be arbitrarily set to 8 feet to continue with the analysis. If $b<2$ feet, set $b=2$ feet and continue. Narrower widths can be used if space is very constrained.

5. **Step 5: Calculate cross sectional area of flow.** Compute the cross-sectional area (A) for the design flow, using Equation 4.

6. **Step 6: Calculate the velocity of the channel flow.**

a. Using the continuity equation (Equation 1), the channel flow velocity can be calculated. The channel flow velocity should be less than 1 fps to prevent grasses from being flattened, which reduces filtration. A velocity lower than this maximum value is recommended to achieve the 10-minute hydraulic residence time criterion, particularly in shorter swales (at V=1 fps, a 600-foot swale is needed for a 10-minute hydraulic residence time and a 300-foot swale for a 5-minute residence time).

b. If the value V suggests that a longer swale will be needed than space permits, investigate how the design flow Q can be reduced; or increase flow depth (y) and/or swale bottom width (b) up to the maximum allowable values and repeat the analysis.

7. **Step 7: Calculate swale length.**

a. Compute the swale length (L) using the following equation:

$$L = Vt_r\,(60 \text{ sec/min}) \qquad \textbf{Equation 10}$$

where: t_r = Hydraulic residence time (in minutes).

b. Use t_r = 10 minutes for this calculation. Swale length may be a matter of local regulation, however length is directly related to achieving the goal of a 10-minute hydraulic residence time. This criterion has been shown to be the optimum value for good removal of particulates, oil, and grease. Performance data from research has indicated that shorter residence times cause a reduction in pollutant removal rates. Longer times may be required if expected pollutant removal efficiency for solids is to exceed 80%.

8. **Step 8: Select swale location.** Options for swale locations may be limited, or may be decided through processes outside the control of the designer. If this is the case, swale geometry should be maximized by the designer, using the above equations, and given the area to be utilized. If the location has not yet been chosen, it is advantageous to compute the required swale dimensions and then select a location where the calculated width and length will fit. If locations available cannot accommodate a linear swale, a wide-radius curved path can be used to gain length. Sharp bends should be avoided to reduce erosion potential. Regardless of when and how site selection is performed, consideration should be given to the following site criteria:

    a. **Soil type.** Soil characteristics in the swale bottom should be conducive to grass growth. Soils that contain large amounts of clay cause relatively low permeability and result in standing water, which may cause grass to die. Compacted soils will need to be tilled before seeding or planting. If topsoil is required to facilitate grass seeding and growth, use 6 inches of the following recommended topsoil mix: 50-80% sandy loam, 10-20% clay, and 10-20% composted organic matter (leaf compost).

    b. **Slope.** The natural slope of the potential location will determine the nature and amount of re-grading, or if additional measures to reduce erosion and/or increase pollutant removal are required. Biofilters should be graded carefully to attain uniform longitudinal and lateral slopes, and to eliminate high and low spots. If needed, grade control checks should be provided to maintain the computed longitudinal slope and limit maximum flow velocity.

    c. **Natural vegetation.** The presence and composition of existing vegetation can provide valuable information on soil and hydrology. If wetland vegetation is present, inundated conditions may exist at the site. The presence of larger plants, trees and shrubs may provide additional stabilization along the swale slopes, but also may shade any grass cover established. Most grasses grow best in full sunlight, and prolonged shading should be avoided. It is preferable that vegetation species be native to the region of application, where establishment and survival have been demonstrated.

9. **Step 9: Select vegetative cover.** A dense planting of grass provides the filtering mechanism responsible for water quality treatment in swales. In addition, grass has the ability to grow through thin deposits of sediment and sand, stabilizing the deposited sediment and preventing it from being re-suspended in runoff waters. Few other herbaceous plant species provide the same density and surface per unit area. Grass is by far the most effective choice of plant material in swales, however not all grass species provide optimum vegetative cover for use in swale systems. Dense turf grasses are best for vegetative cover. Table 6 is provided as an example of the variations in grass species. See the SUDAS specifications for information on the recommended or optimum turf grass species most suitable to the area, based on suitability in terms of cold tolerance, heat tolerance, mowing height adaptation, drought tolerance, and maintenance cost and effort.

    The type of grass cover can be selected at any earlier stage in the design process. Often if grass cover is known, optimum height can be established and flow depths can be set accordingly. In areas of poor drainage, wetlands species can be planted for increased vegetative cover. Use wetland species that are finely divided and relatively resilient, like grass. Use of invasive species should be avoided to eliminate proliferation in the swale and downstream.

10. **Step 10: Check swale stability.** The stability check is performed for the combination of highest expected flow and least vegetation coverage and height.

a. Compute 2-year and 10-year frequency storm event peak discharges using NRCS WINTR-55.

b. Check 2-year velocity for erosive potential (adjust geometry if necessary, and re-evaluate WQv design parameters).

c. Check 10-year depth and velocity for capacity (adjust geometry if necessary, and re-evaluate WQv and 2-year design parameters).

d. Provide minimum freeboard above 10-year stormwater surface elevation (6 inches minimum, recommended).

e. Stability is normally checked for flow rate (Q) for the 100-yr, 24-hour storm unless runoff from larger such events will bypass the swale. Q can be determined using the same methods mentioned for the initial design storm computation.

f. The maximum velocity, V_{max} (fps), that is permissible for the vegetation type, slope, and soil conditions should be obtained. Table 4 provides maximum velocity data for a variety of vegetative covers and slopes.

g. The estimated degree of retardance for different grass coverage (good or fair) should be obtained for the selected vegetation height. Estimation should be based on coverage and height that will first receive flow, or whenever coverage and height are at their lowest. Table 5 provides qualitative degrees of retardance for coverage and grass height.

Table 5: Guide for selecting degree of flow retardance

Average height of grass (inches)	**Degree of vegetation coverage**	
	Good	**Fair**
>25	A (very high)	B (high)
11-24	B (high)	C (moderate)
6-10	C (moderate)	D (low)
2-6	D (low)	D (low)
<2	E (very low)	E (very low)

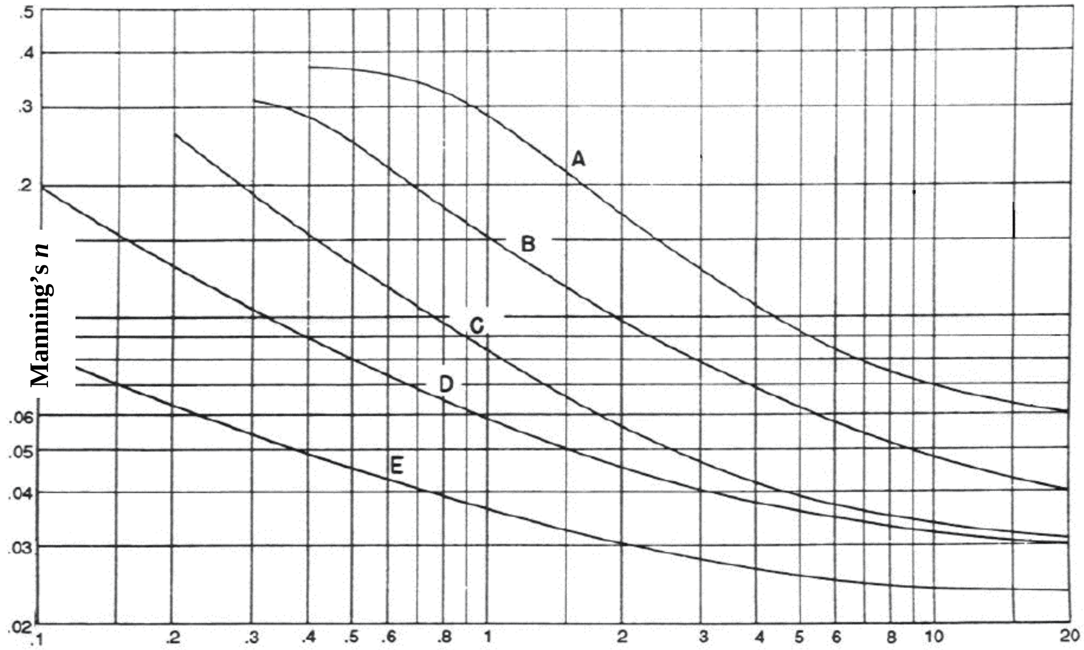
Source: NRCS, 1954

Table 6: Manning roughness coefficients, n, for typical grasses for well-maintained straight channels without shrubbery or trees

Grass Type (1)	**Depth of Flow**	
	0.7-1.5 feet (2)	> 3.0 feet (3)
Bermuda grass, buffalo grass, Kentucky bluegrass		
a. Mowed to 2 inches	0.035	0.030
b. Length 4-6 inches	0.040	0.030
Good stand; any grass		
a. Length of 12 inches	0.070	0.035
b. Length of 24 inches	0.100	0.035
Fair stand; any grass		
a. Length of 12 inches	0.060	0.035
b. Length of 24 inches	0.070	0.035

Source: Chow, 1959

Figure 7: Relation between Manning's n roughness coefficient VR* and degree of retardance**



*VR: product of velocity and hydraulic radius
**Degree of flow retardance due to vegetation: A-very high, B-high, C-moderate, D-low, E-very low

Source: Haan et al., 1994

h. Select a trial Manning's n value for poor vegetation cover and low height. A good initial choice is n=0.04. Using the alpha code assigned for the degree of retardance and the chosen n value, consult the graph in Figure 7 to obtain a first approximation for VR (velocity times hydraulic radius, ft^2/sec).

i. Compute the hydraulic radius, using the V_{max} determined for vegetation type and slope, by applying the following equation:

$R = VR/V_{max}$ **Equation 11**

For precision, the VR value obtained from the graph, in units of ft^2/s, should be converted to metric units by multiplying by a factor of 0.09290 to obtain VR in m^2/s. From Manning's equation (metric):

$V = 1.0/n\ R^{2/3}S^{1/2}$, then

$VR = (R^{1.67}S^{0.5})/n$ **Equation 12**

Once the actual VR is determined, compare this value with the first approximation for VR obtained through Figure 2I-2.7. If they do not agree within 5%, adjust Manning's n value and repeat the process until acceptable agreement is reached. If n<0.033 is needed to get agreement, set n = 0.033, solve VR again using Manning's equation above, and proceed. The actual velocity for the final design conditions should be computed using the following equation:

$V = VR/R$ **Equation 13**

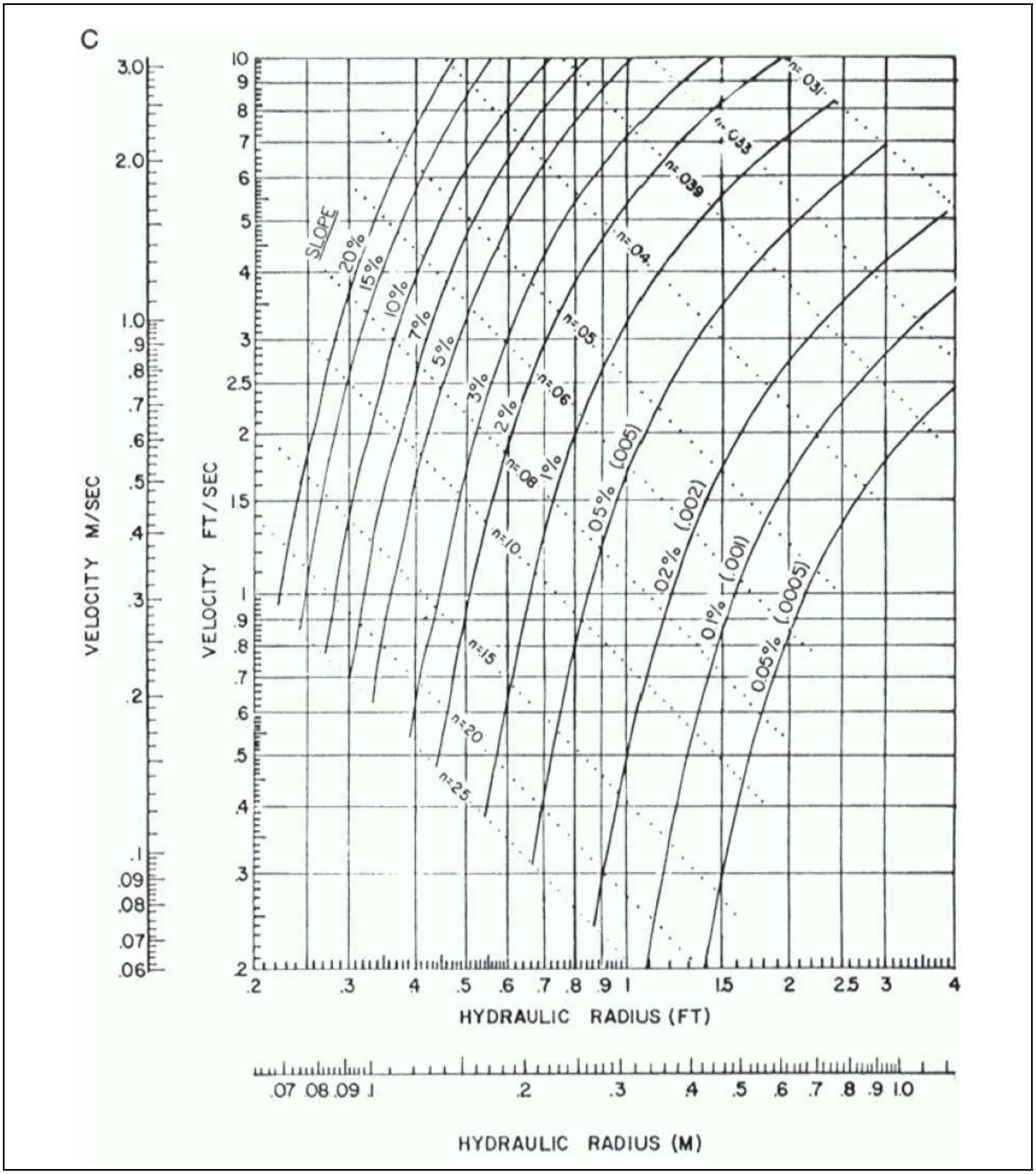
The actual velocity V should be less than or equal to the maximum value obtained from Table 4. The area required for stability is computed using the continuity equation (Equation 1).

The area value obtained in this procedure should be compared with the area value obtained in the design flow analysis. If less area is required for stability than is provided for design flow, the design is acceptable. If more area is required for stability, use the area value obtained in the stability analysis to recalculate channel dimensions and recalculate the depth of flow, solving Equation 4 for y.

This stability flow depth, if needed, should be compared to the depth used in the design flow. The larger of the two values should be used, plus 12 inches (6 inches minimum) of freeboard, to obtain the channel depth (Equation 8).

A final check for capacity should be performed based on the stability check and the maximum vegetation height and cover to ensure that capacity is adequate if the largest expected event coincides with the greatest retardance. Use Manning's equation with Manning's n value used for design flow and the calculated channel dimension (including freeboard) to compute the flow capacity of the channel. If the flow capacity is less than the flow rate of the stability check, increase the channel cross sectional area as needed for this conveyance, and specify the new channel dimensions. Horner (1988) advocated using a parabolic shape for design even if a design for a trapezoidal shape is initially used in construction. A check using the parabolic shape may give an indication of performance at some later date. If there is insufficient space for the grass swale as designed, possibilities include dividing the flow among several swales, installing detention to control release rate upstream, increasing longitudinal slope, increasing side slopes, increasing vegetation height and design depth of flow (design should ensure vegetation remains standing during design flow), and reducing developed surface area to reduce runoff coefficient value and gain space for use of the grass swale.

Figure 8: Solution to Manning's equation for retardance class C



Source: Haan et al., 1994

I. Inspection and maintenance requirements

Table 7: Typical maintenance activities for grass swales

Activity	Schedule
Mow grass to maintain a height of 3-6 inches.	As needed (frequently/seasonally)
Remove sediment buildup in the bottom of the grass swale once it has accumulated to 25% of the original design volume.	As needed (infrequently)
Inspect grass along side slopes for erosion and formation of rills or gullies and correct.	Annually (semi-annually the first year)
Remove trash and debris accumulated in the channel.	
Based on inspection, plant an alternative grass species if the original grass cover has not been successfully established.	

Source: Claytor and Schuler, 1996

Table 8: Example criteria for turf grass cover

	Cold Tolerance	Heat Tolerance	Mowing Height	Drought Tolerance	Maintenance
High	Kentucky bluegrass		Tall fescue		
	Red fescue				
			Red fescue		
			Kentucky bluegrass		
		Tall fescue	Perennial ryegrass		
					Kentucky bluegrass
		Kentucky bluegrass			
		Perennial ryegrass		Tall fescue	Perennial ryegrass
	Tall fescue			Red fescue	
				Kentucky bluegrass	Tall fescue
		Red fescue		Perennial ryegrass	
Low					

Source: Adapted from Young et al., 1996

J. Design example

Trapezoidal Grass Swale

1. **Basic data.** Small commercial lot 300 feet deep x 145 feet wide located in Des Moines, IA.

   a. Drainage area (A) = 1 acre

   b. Impervious percentage (I) = 70%

   c. Rv = 0.05 + (0.009)* (I) = 0.68

2. **Water quality peak flow.** (See Section 2C-7 for details).

   a. Compute the water quality volume in inches:

   WQv = 1.2 (0.05 + 0.009 * 70) = 0.82 inches

   b. Compute modified CN for 1.25-inch rainfall (P=1.25 inches)

   CN = 1000/[10+5P+10Q-10(Q2+1.25*Q*P)½]

   = 1000/[10+5*1.25+10*0.82-10(0.822+1.25*0.82*1.25)½]

   = 96.49 (Use CN = 96)

   c. For CN = 96 and an estimated time of concentration (t_c) of 8 minutes (0.13 hours), compute the Qwq for a 1.25-inch storm.

   Compute Qwq using NRCS WINTR-55:

   Qwq = 1.24 cfs

   d. Compute Q_2 and Q_{10} using CN=87 for this site (70% impervious urban commercial site with B soils) and t_c = 0.13 hr: WINTR-55 results:

   Q_2 = 2.42 cfs Q_{10} = 4.14 cfs Q_{100} = 7.17 cfs

3. **Use Qwq to size the channel.** The maximum flow depth for water quality treatment should be approximately the same height of the grass. A maximum flow depth of 4 inches is allowed for water quality design. A maximum flow velocity of 1 fps for water quality treatment is required. For Manning's n, use 0.15 for medium grass, 0.25 for dense grass. Longitudinal slope is 2%. Grass will need to be maintained at a 6-inch height. Trapezoidal channel with side slope of 4:1 (z = 4.0). Tall fescue will be used as the grass type.

   a. Input variables:

   n = 0.15
   S = 0.02 ft/ft
   D = 4/12 = 0.33 ft

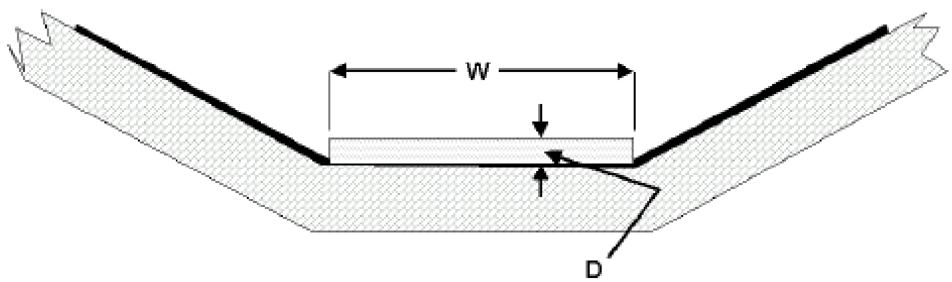
b. Then:

   $Qwq = Q = V \times A = [1.49/n\ D^{2/3}\ S^{1/2}] \times DW$

   where:
   Q = peak flow (cfs)
   V = velocity (fpsec)
   A = flow area (ft2) = WD
   W = channel bottom width (ft)
   D = flow depth (ft)
   S = slope (ft/ft)

   Note: D approximates hydraulic radius for shallow flows.

Figure 9: Using Qwq to size a channel



c. Then for a known n, Q, D, and S minimum width can be calculated.

   $(nQ)/(1.49\ D^{5/3}\ S^{1/2}) = W = (0.15*1.24)/(1.49*0.33^{5/3}*0.02^{1/2}) = 5.6$ feet min. (use 6 feet)

   $V = Q/(WD) = 1.24\ ft^3/sec/(6\text{-}ft * 4/12\text{-}ft) = 0.62$ fps (okay: < 1 fps)

   Note: WD approximates flow area for shallow flows.

   Minimum length for 5-minute residence time, L = V * (5*60) = 186 feet (~372 feet for t = 10 minutes).

d. Depending on the site geometry; the width, slope, or density of grass (Manning's n value) might be adjusted to slow the velocity and shorten the channel in the next design iteration. For example, using an 8-foot bottom width* of flow and a Manning's n of 0.25, solve for new depth and length.

   $Q = VA = 1.49/n\ D^{5/3}\ S^{1/2}\ W$

   $D = [(Q * n)/(1.49 * S^{1/2} * W)]^{3/5}$
   $= [(1.24 * 0.25)/(1.49 * 0.02^{1/2} * 8.0)]^{3/5} = 0.36$ ft (okay: < 4 inches)

   $V = Q/WD = 1.24/(8.0 * 0.36) = 0.43$ fps

   L = 0.43 fps * 5 min * 60 sec/min = 129 feet

   For a velocity of 0.62 fps, a channel bottom width of 6 feet, flow depth of 4 inches, and Q = 1.24 cfs

A = 1.24 ft3/sec / 0.62 fps = 2 ft^2

4. **Check for stability and capacity at the computed dimensions.**

a. Q_{10} = 4.14 cfs and Q_{100} = 7.17 cfs. From design flow, width of channel bottom is 6 feet. Base the check on a grass height of 6 inches and with fair coverage. From Table 5, the degree of retardance is category D. The soils are HSG B soils and will be erosion-resistant. The maximum velocity (V_{max}) is 6 fps (1.80 m/sec) from Table 4. Select a trial Manning's n value of 0.04, which corresponds to a VR value (velocity x hydraulic radius) of 3 ft^2/sec using Figure 7. Convert the VR value to metric units:

$VR_{metric} = VR_{english}$ x 0.0929 = 3 ft^2/sec x 0.0929 = 0.28 m^2/sec

b. Calculate the hydraulic radius, R, using Equation 12:

R = 0.28 m^2/sec / 1.80 m/sec = 0.15 m (0.47 feet)

c. Using the computed hydraulic radius, calculate the actual VR using Equation 12:

VR = $(0.15 \text{ m})^{1.67}$ x $(0.02)^{0.5}$ / 0.04 = 0.16 m^2/sec (1.68 ft^2/sec)

The estimated VR value, 3 ft^2/sec, is not within 5% of the computed VR value, 1.68 ft^2/sec. Using a new Manning's n value of 0.036, from Figure 5, the new estimated VR is 6 ft^2/sec (0.56 m^2/sec). The recalculated R from Equation 10 is 0.31 m (0.98 feet) and the recalculated VR from Equation 12 is 0.55 m^2/sec (5.92 ft^2/sec). The new value is within 5% of the estimated value of 0.56 m^2/sec, so proceed with stability check.

d. The actual velocity for the new design is recomputed using Equation 13:

V = 0.56 m^2/sec / 0.31 m = 1.80 m/sec (5.91 fps)

The actual velocity is less than the estimated maximum velocity of 6 fps from Table 5, and the stability check can proceed.

e. Calculate the X-section area to test stability using the continuity equation:

A = Q_{100} / V = (7.17 ft^3/sec) / (5.91 fps) = 1.21 ft^2

The stability area of 1.21 ft^2 is less than the original calculated flow area of 2 ft^2, so can proceed to the capacity check. If the stability area was larger, then would need to select a new trial size and flow depth and recalculate the X-section area of flow until this condition is met.

f. The channel dimensions, including freeboard, are used to compute the flow capacity of the channel. The greater of the two flow depths from the design flow or stability check should be used. In this example, the stability check flow depth of 0.98 feet is greater than the design flow depth of 0.33 feet (4 inches). Using Equation 8:

H = y + freeboard = 0.98 ft + 1 ft = 1.98 ft

g. Using Manning's equation, the Manning's n value selected in the design flow (0.15) and the channel dimensions, recompute the flow capacity for the channel. Using Equation 4, and using H for Y:

$A = by + zy^2 = (6.0\text{-ft})(1.98\text{ ft}) + (4)(1.98\text{ ft})^2 = 27.56\text{ ft}^2$

Substituting Equation 6 into Equation 7 (using H for y):
$R = A/P = 27.56\text{ft}^2 / [6\text{ ft} + (2)(1.98\text{ ft})(1+4^2)^{0.5}] = 1.54\text{ ft}$

Using Equations 1 and 2 (n = 0.15, S = 0.02):

$Q = (27.56\text{ ft}^2) \times (1.49)(1.54\text{ ft})^{0.667} \times (0.02)^{0.5} /0.15 = 51.64\text{ ft}^3/\text{sec}$

The flow capacity of 51.6 ft^3/sec for the swale is greater than the stability check flow rate of 7.17 ft^3/sec for the 100-yr storm, provided in the example site data.